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The Effect of Visual Stimulus Traces on Memory

ALLAN MEAKIN COLLINS

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13. ABSTRACT

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Improvement with repetition was found both for report and for recognition of non-reported letters over VCs. There was no improvement for recognition of non-reported letters over ACs. The improvement in report was small, about 2.5% over three repetitions and was fairly uniform for all positions in the row. The improvement in recognition over VCs was about 5% over three repetitions and occurred entirely in the last four positions of the row. The different pattern of improvement in these two cases suggested that improvement in recognition over VCs probably was based on an increase in letters seen on each repetition, whereas the improvement in report was based on a long-term accumulation, probably of response integration.

T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS

DEPARTMENT OF PSYCHOLOGY

THE EFFECT OF VISUAL STIMULUS TRACES ON MEMORY

Allan Meakin Collins

HUMAN PERFORMANCE CENTER--TECHNICAL REPORT NO. 27

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PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human processing and retrieval, supported by the Advanced Research Projects Agency, Behavioral Sciences, Command and Control Research, under Order No. 461, Amendments 3 and 5, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract No. AF 49(638)-1736.

This report was also a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1970. The doctoral dissertation committee was: Drs. E. Martin, Chairman, T. G. Birdsall, A. W. Melton, and W. R. Reitman.

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ABSTRACT

Haber (1967) has found that repeatedly flashing a word in a tachistoscope for the same brief duration each time leads to improved report for the letters in the word. What kind of memory makes it possible to report a letter on one trial that was not reported on the previous trial, considering that other experimenters find no memory for briefly flashed rows of letters when they are not reported?

In this experiment, rows of eight letters were briefly flashed to Ss. Some rows were presented two or three times with from 0 to 3 intervening rows between each repetition. The Ss first reported (in writing) as many letters as possible and then were given a forced-choice recognition test for one of the letters in the row. The incorrect alternative in the forced choice was either an auditory confusion (AC) or a visual confusion (VC) for the correct letter.

Improvement with repetition was found both for report and for recognition of non-reported letters over VCs. There was no improvement for recognition of non-reported letters over ACs. The improvement in report was small, about 2 1/2% over three repetitions, and was fairly uniform for all positions in the row. The improvement in recognition over VCs was about 5% over three repetitions and occurred entirely in the last four positions of the row. The different pattern of improvement in these two cases suggested that improvement in recognition over VCs probably was based on an increase in letters seen on each repetition, as Haber has found, whereas the improvement in report was based on a long-term accumulation (probably response integration) of the kind found by Hebb (1961) and Melton (1963). The increases in this experiment with rows of letters were much smaller than the increases Haber has found for words. This is attributed to two factors: The unpredictability of the repetitions in this experiment and the fact that increases of letters seen would lead to an increased load on rehearsal in this experiment and a decreased load in Haber's experiments where the word could be encoded as a single unit.

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CHAPTER I

INTRODUCTION

The Relation Between Stimulus Traces and Long-Term Memory

Sperling (1960) and Averbach & Coriell (1961) discovered that when an array of letter is flashed very briefly (on the order of 50 msec), instead of disappearing immediately upon termination of the display, the visual image appears to decay over a period of from 300 to 1000 msec, when there is no afterimage. This rapidly decaying visual image is generally regarded as a visual buffer storage or stimulus trace.

The technique used by Sperling in his original study of this phenomenon was to display three rows of letters, usually with four letters in each row. He cued the S auditorily as to which of the rows he should report by presenting one of three tones. The onset of the auditory cue was varied systematically from before the display onset to 1 sec. following the termination of the display. Sperling found that report declines monotonically from a peak of about 90% correct when the tone coincides with the display termination to a minimum level of about 30% when the tone is delayed for 1 sec. This minimum corresponds to the level of report found when the S is asked to report all twelve letters as best he can, without cuing any particular row.

Sperling (1963, 1965) later presented a model (somewhat modified in the latter paper) of what an S does in this kind of task. He postulatos three basic processes: (1) a visual information storage system (VIS)

which decays rapidly, and acts as a buffer system, (2) a scanning process by which the S reads the letters out of VIS at a rate of approximately 100 per sec, into (3) a rehearsal loop in which the S maintains the letters in auditory information storage (AIS) by saying them over to himself at a rate of 3 to 10 per sec. To account for the disparity in rates between scanning and rehearsal, Sperling assumes that the scanning process can hold a certain number of items until the S is ready to rehearse them. He implicates the slowness of the rehearsal process as the reason why people can only report four or five letters, when more than five letters are flashed in such a procedure.

Sperling refers to VIS as a buffer system, but there are at least two kinds of storage systems that would have the properties of decay he found. In one system, that implied by Sperling though not directly assumed, VIS would be a separate memory system, entirely distinct from long-term memory. In order then to record anything into long-term memory, it would be necessary to transfer it (by scanning or reading out, in Sperling's terms) from buffer storage to long-term memory. In Sperling's model, VIS functions solely as a buffer storage and AIS as a long-term storage, but if he had tried to account for auditory inputs as well, he might have postulated a separate auditory buffer storage. While this interpretation is not clearly Sperling's intention, it is one plausible implementation of the scheme he outlined, and parallels the one used in computer systems from which the term "buffer storage" is derived.

Hebb's (1949) dual trace mechanism offers an alternative formulation of the relation between stimulus traces and long-term memory. In Hebb's account, stimulation sets up an activity trace in neural networks (cell assemblies), and this activity trace is directly involved in effecting material changes which are the basis for long-term memory. Retrieval from long-term memory, in this view, involves a reactivation of the same networks that were involved in the activity traces. Thus, activity traces and material traces are two forms of memory, but <u>within the same networks</u>.

There is no incompatibility between this kind of notion and the transferring of information from visual to auditory memory. In Hebb's framework, this transfer to auditory memory would be a selective activation of traces in auditory memory corresponding to the activity traces stimulated in visual memory. Such a process might better be termed an addition to auditory memory rather than a transfer to auditory memory. However, if Sperling is correct that people rehearse letters and numbers in auditory memory rather than in visual memory (visual rehearsal may be what is called imaging or picturing), than activity traces in visual memory would die out rather quickly while those in auditory memory would be continually reactivated.

Since for most adults numbers and letters (and different orderings of them) are so well-learned, Hebb (1961) thought that activity traces produced by such stimuli would have no significant effects in altering the already well-established neural interconnections. To test this notion he used a recall experiment where nine-digit strings were presented auditorily. On each trial he presented a new nine-digit string, except that one string

was repeated every third trial. He expected to find no improvement in recall with repetition, but to his surprise the repeated string was recalled better as it was repeated more. When Melton (1963) replicated this experiment using visual inputs, he found improvement with up to eight intervening strings. As Melton states, "I must concur with Hebb's conclusion that his experiment demonstrates the fixation of a structural trace by a single repetition of an event . . . the data from both short-term memory and long-term memory tempt one to the radical hypothesis that every perception, however fleeting and embedded in a stream of perceptions, leaves its permanent 'structural' trace in the CNS. [p. 19]"

Therefore, it is apparent that activity traces set up by well-learned stimuli such as letters or numbers do lead to long-term traces of some kind. But the results of Sperling, and Averbach & Coriell show that even briefly flashed visual stimuli set up activity traces, which can be detected if one probes soon enough. While these activity traces are of very short duration, even as compared with those in the Hebb and Melton experiments, they should, under the dual trace hypothesis, have some kind of long-term effect, though surely a very weak one. If this hypothesis is correct, then, a sensitive-enough test should be able to detect the long-term changes produced by the activity traces in the Sperling paradigm, even where the letters were not cued for report and were not reported.

<u>Evidence as to Long-Term Effects of Stimulus Traces</u>

The experimental evidence with respect to the long-term effects of non-reported stimuli has, for the most part, been negative. In one sense

the evidence against subliminal perception (McConnell, Cutler, & McNeil, 1958) can be taken as evidence against any long-term effects of non-reported materials, but in this literature it is not clear that the subliminal stimuli used are even strong enough to set up a stimulus trace of the kind that Sperling, or Averbach & Coriell have found.

In order to test whether stimulus traces from non-reported letters have any long-term effects, Glucksberg & Balagura (1965), using a Sperling-type array with a 50 msec exposure, repeated the same row of letters a large number of times. The repeated row varied over trials from one position to another, but was never cued. The remaining rows, one of which was always the one cued, changed from trial to trial. When the reported row was finally cued for report, the letters in it were reported with no more accuracy than those in a new row. This study, then, found no long-term effect from non-cued rows.

In a pilot study using the same paradigm, I repeated a non-cued row on five consecutive trials, but in a different position each time. Then the Ss were given a two-alternative forced-choice between two rows of letters, one of which was completely new and one of which was the repeated row. The Ss had no way of knowing beforehand that a row would be repeated nor that there would be a memory test afterwards. After they had completed the five trials, the Ss were told about the repeated row and that they were to choose it from the two alternatives on a card. Subjects picked out the repeated row in about 85% of their choices. The large number of intrusions from the repeated row in the Ss' report on the five trials offered a possible explanation of their ability.

of their ability to make the correct choice. When given the forced-choice, the Ss probably chose the row that contained any letters they remembered from their previous reports. Thus, this experiment was not evidence of a long-term memory for letters not reported. However, the result does suggest that the failure of the Glucksberg & Balagura experiment to show any effect of repetition probably lies in not using a sensitive-enough test.

In a similar vein Turvey (1967) attempted to see if the Hebb and Melton findings carry over to the Sperling paradigm. Turvey ran Ss for four days on a task in which he displayed with slides a three-by-five array of letters for 50 msec on each trial. The Ss were cued auditorily to report one of the rows. On the first three days of preliminary training a new array was presented on every trial. On the fourth day Turvey repeated the same slide 54 times with a new slide interpolated between each repetition. The row cued for report on that slide varied randomly from repetition to repetition. Turvey found no significant effect of repetition, but for the last three blocks of trials (out of six) on the fourth day of both replications he ran, the report of the row from the repeated slide was better than or equal to (in one case) report for the non-repeated slide. This makes his acceptance of the null hypothesis, that there was no improvement with repetition, look rather tenuous.

In order to explain his failure to find improvement with repetition, as did Hebb and Melton, Turvey hypothesized a difference in encoding between the two kinds of experiments. His argument was that the Ss do not encode the repeated stimuli in the Sperling paradigm, whereas the Ss in the Hebb

and Melton experiments are forced to encode the stimuli. However, Turvey's Ss were forced to encode at least the cued row in the repeated slide. They read the cued row and then reported it (or tried to), which is exactly what Melton's Ss were required to do. The only differences between the two procedures were that Turvey presented shorter rows for less time, together with other rows the S was supposed to ignore. In the Turvey experiment there were on the average five intervening slides between repeated cuings of the same row, since any row on the repeated slide would be cued on one-third of the repetitions. The combination of such a large number of intervening rows between repeated cuings of the same row, and the short exposure time may explain his failure to find significant improvement.

Turvey may be correct that the Ss fail to encode the non-cued rows. This failure may lead to the result that non-cued rows have no effect on long-term memory except to the degree that intrusions occur in report from the non-cued rows. Whether in fact non-cued and non-reported letters have any effect on long-term memory is in part what we want to find out, and it is clear that Turvey's kind of test is not a very sensitive one either.

In audition the results of attempts to find any long-term traces from non-attended stimuli have also been negative. Using dichotic inputs, Moray (1959) had Ss shadow verbal material in one ear, while common English words were repeated 35 times in the other ear. The repeated words were started after and finished before the material to be shadowed. A recognition test within thirty seconds of the end of the shadowing task found no evidence that any of the words repeated in the non-attended ear were remembered

at all. There was one exception to this result. About one-third of the Ss whose name was presented to the other ear remembered it when questioned later. The most likely explanation for this is that the Ss detected their names when presented and so they attended to them long enough to leave a permanent trace. In any case the memory for the presentation of their own names would seem to indicate that at least an activity trace was set up by the material presented to the non-attended ear.

Norman (1968) varied Moray's procedure by presenting six pairs of digits to the non-attended ear while the S shadowed a message to the other ear. The S was interrupted by a tone from shadowing, and 20 sec later a target pair of digits was presented. The S was required to decide whether or not the target pair was among the six pairs presented to the non-attended ear. Performance on this recognition task was at chance level, just as Moray had found. However, when Norman tested for recognition with the target pair immediately after the tone interrupted the shadowing, and within seven seconds of when the first digit pair was presented to the non-attended ear, then recognition was well above chance. Except for the difference in time order of decay, the analogy across modalities between this experiment and the Sperling experiment is quite striking.

It therefore appears as if material presented to the non-attended ear enters a buffer storage or sets up an activity trace just as in vision. If one probes soon enough, as Norman did in the latter condition, the material can be retrieved from buffer storage (or the activity trace). However, if the probe is not made till after the trace has decayed, then both the Moray

and Norman studies indicate the material is lost. It should be emphasized that both these experimenters used the most sensitive test possible.

There is one exception to this generally negative evidence. In a series of studies (Haber, 1965; Haber & Hershenson, 1965; Hershenson & Haber, 1965) Haber has shown that consecutive repetition of briefly flashed words does indeed lead to improved report. This finding is in contrast to Turvey's finding, but the consecutive repetition used by Haber was much more likely to produce improvement than Turvey's method.

Haber for the most part used seven letter words which he displayed for variable durations of 15 to 25 msec. The durations used were constant across repetitions and were below the level where the Ss could read all the letters on the first trial. He instructed the Ss to report only those letters they actually saw, even when they had figured out what the word was. He found generally that the probability of reporting the whole word correctly increased with repetition (usually by over 50%), with most of this increase occurring in the first five repetitions. Even though he used high frequency and low frequency words, English and Turkish words for English speaking Ss, and in one condition showed the Ss the words in advance, he always found the same basic curve for improved report with repetition. The different conditions only acted to shift the asymptote of the curve up or down.

Because no other model seemed to handle these effects of repetition, Haber (1967) adopted a modified Hebbian model to explain the repetition effect he found. He argued that repeated stimulation near the threshold

boosts the activity by degrees in already well-established cell assemblies. This must mean that he interprets his findings as an accumulation of activity traces, rather than a longer-term accumulation. He therefore would probably not expect any increase if an intervening row were inserted between repetitions.

Haber's results, however, are not clear evidence for the kind of accumulation he has suggested. There are at least two other hypotheses that would account for the increases found. (1) The attention hypothesis. The S's attention shifts from trial to trial and thus on each trial different stimulus letters are most likely to be seen. When a letter has been reported, learning occurs, and it takes less attention to see that letter on following presentations. On this hypothesis, there would be no learning other than for the letters reported on any trial, and if attention were fixed, then the same letters would always be reported. (2) The long-term accumulation hypothesis. On each trial, activity traces elicited by each of the letters lead to long-term changes that accumulate in visual memory from trial to trial until the activity trace elicited by the stimulus is strong enough to be remembered and reported. On this hypothesis, no shift of attention is required for improvement, because even letters that are not reported become more likely to be reported as the stimulus is repeated. These two hypotheses are not contradictory so that the improvement in Haber's studies could result from both kinds of learning.

In a later study, Haber & Hillman (1966) used single letters as stimuli in order to disprove the attention hypothesis. They still found marked

improvement with repetition. But even with single letters, attention shifts might lead to improved report, so that they have not in fact disproved this hypothesis. However, this study does make it very doubtful that attention shifts are the only source of improvement with repetition.

A Test for Long-Term Effects of Visual Stimulus Traces

With a modification of Haber's basic procedure, it seemed possible with this study to ascertain whether his findings are produced (in whole or in part) by accumulation of long-term traces in visual memory. Instead of displaying words for about 20 msec, a single row of eight letters was displayed for 50 msec. Subjects were instructed to report as many letters as possible. Under the Sperling model a reported letter must be transferred to AIS and rehearsed there. Thus letters not reported should show no accumulation since they are never transferred out of buffer storage. In contrast, under the Hebb model these activity traces should lead to a long-term accumulation even for non-reported letters.

To test if in fact accumulation occurs when a letter is not reported, it was decided in this experiment to probe individual positions with a two-alternative forced-choice recognition test after the S had completed his report of the row. Any accumulation should show up as an increasing percentage of recognitions for non-reported letters. Furthermore, a test of whether the accumulation occurs in visual memory can be made by using either an auditory or a visual confusion as the incorrect alternate choice in the recognition test. If there is an accumulation of partial visual information (e.g., the letter had a point at the bottom) about non-reported

letters, than this information should be more useful for distinguishing the correct letter (e.g., V) from an auditory confusion (e.g., B) than from a visual confusion (e.g., Y). Hence, it was predicted that an accumulation in visual memory with repetition should lead to a greater increase in correct recognition over auditory confusions than over visual confusions for non-reported letters.

To isolate whether attention shifts were partially responsible for the increases Haber found, the repetition of rows was made impossible for the Ss to anticipate. This was accomplished by varying the number of repetitions from zero to three. In this way it was also possible to test if the Haber effect is extremely transient (as he seems to suppose) and dependent upon the repetitions following one after the other. If there should be an increase only for the condition when there are no intervening rows, then it would appear as if some kind of accumulation of activity traces rather than long-term traces is involved.

The experiment then has three basic goals: to understand the basis for increased reports in the Haber experiments, to clarify the role of auditory and visual memory in tasks such as the Sperling and Haber experiments employed, and most importantly to explore the relationship between the stimulus trace and long-term memory.

CHAPTER II

METHOD

Subjects

The *S*s were 128 University of Michigan undergraduate and graduate female students who volunteered for paid participation.

Procedure

The experimental session consisted of 112 trials, of which the first eight were practice trials. Each trial consisted of two parts. In the first part a row of eight letters was flashed for 50 msec in a tachistoscope. The top half of Fig. 1 illustrates a typical row as it appeared to the *S*s.

About 1 sec before the row was flashed the *E* said "Ready" and immediately pressed a button (which was quite audible) starting the tachistoscope in its cycle. The flash followed the button press at a fixed interval of less than .5 sec. As soon as possible after the flash, the *S* wrote down as many of the letters as she could on an answer sheet provided with eight spaces. The *S* was instructed to put the letters in the proper spaces as best she could. When finished, she turned the answer sheet face down into a box so that she could not refer to it later.

The second half of the trial was a recognition test for a single letter in the row just flashed. Two letters were displayed at length in the tachistoscope, with a particular position in the row indicated. The bottom half of Fig. 1 shows how this recognition test appeared to the *S*s. One of the two letters had appeared in the presented row in that position, and

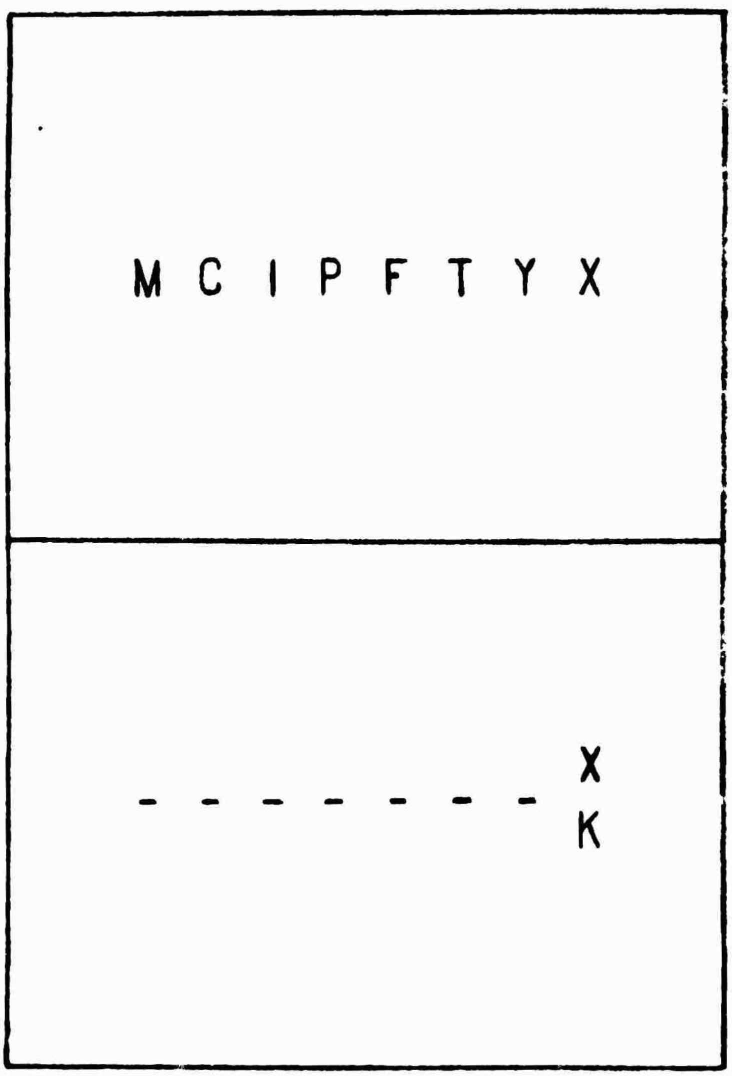

Fig. 1. Examples of a stimulus card (top) and a forced-choice recognition test card (bottom).

the S was forced to choose which one. She responded by both writing her choice on another answer sheet and telling the E, who also recorded the choice. The S's record was used in analyzing the data, except where there was uncertainty as to which letter the S had written. When the S responded the two choices were removed from the tachistoscope and the next trial began.

Apparatus and Materials

The S sat at a table and looked into a Gerbrands two-channel mirror tachistoscope. A background field was a uniform light gray with a fixation point just to the left of where the row of eight letters was flashed for 50 msec. The row of letters was centered in the visual field, extending 2 1/2 in. from left to right. Since the viewing distance was 23 in., the row subtended a visual angle of 6°. The letters were all capitals, and were typed on white index cards in Bulletin Type. The letters were 3/16 in. high (27' visual angle) and 1/8 in. wide (18') on the average, with a space of 3/16 in. (27') between each letter.

On the cards used for the recognition test, dashes were typed in each position where a letter appeared in the row, except in the position that was being probed. In this position two letters appeared, one above and one below the line. They were typed in the same type face.

Intervening and Repeated Rows

Data were collected for 64 intervening rows, which were shown only once, and 16 repeated rows, which were each shown either two or three times.

Eight of the repeated rows were shown three times each for a total of 24 trials. The other eight were shown two times each for a total of 16 trials. In total, then, there were 40 trials in which repeated rows appeared. These, together with the 64 trials on which intervening rows appeared, made up the session total of 104 experimental trials.

Between each presentation of a repeated row there were either 0, 1, 2, or 3 intervening rows. When a row was presented three times, the number of intervening rows between the last two presentations was the same as between the first two presentations. Equal numbers of both twice repeated and thrice repeated rows appeared with 0, 1, 2, and 3 intervening rows.

Construction of the Intervening Rows

The same set of 64 intervening rows was used for all 128 Ss. After every two Ss, however, the order of these rows was randomly rearranged by shuffling the cards. In this way any letter in one of the eight positions for a particular row was likely to be preceded for different Ss by a variety of letters in that position in the previous row.

In the 64 rows, each of the 25 letters (excluding Q, which was not used in the experiment) appeared at least two times and no more than three times in each position. For both intervening and repeated rows no letter appeared more than once in a row. Furthermore, each diad of letters used in an intervening row (for instance MC in MCIPFTYX) appeared only once among the 64 rows. Care was taken to prevent combinations of letters that were meaningful.

Construction of the Repeated Rows

There were eight different sets of repeated rows, and each set was used for 16 different Ss. Among the 16 rows within a set, each letter was used at least five times and appeared in a particular position no more than once. Each set of 16 was constructed so that no diad occurred in exactly the same position as in an intervening row. As much as possible, different diads were used in repeated rows, and when a diad was used that also occurred in an intervening row, its use was limited in almost all cases to a position in the row two letters away or more from its position in the intervening row. This effort was made so that, for example, MCIPFTYX would never be followed by a row such as MCRLPNZY. Over the eight sets of 16 repeated rows, each letter appeared in each position at least four times.

The Sequence of Rows Presented

In constructing the sequence of intervening and repeated rows for the experimental trials, all the occurrences of one repeated row were completed before the first presentation of the next repeated row (i.e., a non-overlapping sequence was used). The particular sequence was changed after every two Ss. To describe the various sequences used, only the first 16 Ss need be considered, because all other Ss had one of the eight sequences used by the first 16 Ss. For example, Ss 17, 18, 33, 34, ... , 113, and 114 had the same sequence of intervening and repeated rows as Ss 1 and 2, although the order of the intervening rows was changed and the repeated rows were different. All eight sequences started with three intervening

rows, followed by the first occurrence of a repeated row on the fourth trial. There were eight different combinations of two and three repetitions with 0, 1, 2, and 3 intervening rows. For each of the eight sequences, a different one of these combinations was used initially. If, for instance, the first occurrence started a 3-1 (3 repetitions, 1 intervening row) combination, the row shown on the fourth trial would also be shown on the sixth trial and the eighth trial. Intervening rows, of course, were shown on the fifth and seventh trials. Whenever the number of intervening rows was either 0 or 1, the last repetition was followed by two intervening rows before starting the next repeated row, whereas if the number of intervening rows was 2 or 3, the next repeated row was shown after one intervening row. In the example of an initial 3-1 combination, where the last repeated row was on the eighth trial, the next repeated row would start on the eleventh trial with two intervening rows occurring on the ninth and tenth trials.

In constructing each sequence of rows, all eight combinations (2-0, 2-1, 2-2, 2-3, 3-0, 3-1, 3-2, 3-3) were used once prior to the second occurrence of any of the eight combinations. Over the eight sequences used, the order of the eight combinations on the first occurrence was varied in a latin square design. The second occurrences of each combination appeared in an order which was a simple transformation of the order of the first occurrences (i.e., 4, 3, 2, 1, 8, 7, 6, 5). This counterbalancing insured that each combination of number of repetitions and number of intervening rows would appear equally often in each position of the sequence of combinations.

Construction of Recognition Choices

On each recognition trial, one of the two letter choices was always correct. The other choice was a letter which was either an auditory confusion (AC) or a visual confusion (VC) with the correct letter. The incorrect choice never appeared in the presented row. In Table 1 are shown the VC and AC choices used for each letter (the basis for these choices is given in the next section). Where two letters appear either letter was used in constructing the recognition choices, though preference was given to the first choice if it did not appear elsewhere in the row. The correct choice was assigned randomly with equal likelihood to the top and bottom positions.

The recognition choices for the 64 intervening rows remained fixed throughout the experiment, so that whenever the row MCIPFTYX appeared, the choice given the S was between X and K in the eighth position. Of the 64 incorrect choices half were ACs and half were VCs. Each correct letter was used at least once in an AC trial and once in a VC trial, and at most three times in the 64 trials. The two or three appearances of a letter as the correct choice in the 64 recognition trials were always in different positions.

For each set of 16 repeated rows used, on the first and second repetitions all of the letters in each position were probed for two of the Ss, one with an AC as the alternative and one with a VC as the alternative. For instance, if a row was presented twice, and one S was probed for the fourth letter with an AC as the alternative the first time, and for the

TABLE 1

Visual and Auditory Confusions Used[a]

Letter	VC	AC
A	X-5. R-3	J-1, H-0
B	O-4, S-2	V-0, P-0
C	O-3	Z-0, E-0
D	O-6, U-6	T-0, E-0
E	L-6, F-3	D-0, T-0
F	T-8, P-5	S-0, X-0
G	S-4, O-4	E-0, D-0
H	N-5, U-3	A-0, X-0
I	T-6, J-4	Y-2
J	U-6	A-0, K-1
K	R-6, N-2	J-0, A-0
L	I-2	R-0, A-0
M	U-10	F-0
N	H-5, S-3	M-1
O	D-5, G-6	A-0
P	F-3, R-3	B-1, T-1
R	P-2, K-2	I-0
S	G-3, J-3	F-0, X-1
T	I-7, F-3	D-0, P-1
U	J-4, O-3	W-0
V	Y-4, U-5	B-0, E-0
W	M-3, N-4	U-0
X	K-5, A-3	S-0, F-0
Y	T-6	I-0
Z	J-6, I-2	C-0, G-0

[a]The numbers are the frequency of visual confusion errors in the preliminary test.

seventh letter with a VC as the alternative the second time, then the other _S_ would first be probed for the fourth letter with a VC as the alternative, followed by the seventh letter with an AC as the alternative. For the third repetition it was possible to probe only half the positions for each row within a set, but across the eight sets all positions were probed equally often. Over the eight sets the positions probed were also balanced with respect to the sequence of combinations of number of repetitions and number of intervening rows. Thus the recognition trials were completely balanced for position in the row, auditory and visual confusability, repetition number, number of intervening rows, and position in the sequence of rows.

Choice of Visual and Auditory Confusions

ACs were chosen to minimize visual confusability, and VCs likewise were chosen to minimize auditory confusability. Since Wickelgren (1965) has shown that letters with a common vowel sound are a large source of errors in a short-term memory task, common vowel sound was the major basis for choosing the auditorily confusable alternative. Where several letters had the same vowel sound, such as E, P, V, B, T, Z, and C, the AC choices were determined by point of articulation. Where a letter had no common vowel sound with another letter, Conrad's (1962) table of confusions in an auditory transmission task was used as the basis for choosing the most auditorily confusing letter.

Visual confusability was determined for the character set produced by the Bulletin typewriter in a preliminary test using 13 graduate students

as Ss. This test consisted of going through the alphabet three times in a random order, showing a single letter each trial at a near-threshold duration. This duration was determined by a trial-and-error procedure with several letters. The S was instructed to make one or two choices as to which letter was shown. The results of this test are reported in Table 2. The table shows the different letters that were given in error as choices to the stimulus letter, and the number of Ss who gave that choice at least once. Those choices that occurred most frequently were used as VCs if they were low in auditory confusability with the correct letter. The numbers given in Table 1 for each VC and AC are the visual confusability scores obtained in this preliminary test. The objective, as indicated, was to minimize these scores for the AC letters, and maximize them for the VC letters.

Instructions to the Subject

The following comments were included in the instructions to the S.

> Some of the rows will be the same as previous rows shown; most will not. Don't let this concern you. Just do the best you can on the basis of the eight letters shown on the current trial. Please don't try to anticipate when a row will be repeated, because you are much more likely to be wrong than right. It is important for the experiment that you work from left to right, fixing your eyes on the left-most letters on each trial. There is really no better strategy, since you are used to reading from left to right, and working from the end helps keep the letters in the right positions.

It is evident from the letters reported that on most trials the Ss did focus on the left end of the row, though almost all Ss focused on the center or right for a few trials.

TABLE 2

Letters Given in Error to Near Threshold Exposures of the Stimulus Letter[a]

Stimulus Letter	
A	K-6, X-5, R-3, B, C, I, J, M, N, S, V, Y, Z
B	O-4, D-3, G-3, S-2, C, H, J, N, R, U, W
C	G-10, O-3, D-2, B, F
D	O-6, U-6, R-3, B-2, G-2, J, S
E	L-6, F-3, C-2, G-2, J, S, T, U, V, X
F	T-8, P-5, E-3, J-2, I, K, U
G	C-5, O-4, S-4, B, U
H	N-5, U-3, M-2, B, C, G, I, K, L, V, Y
I	T-6, J-4, L-2, Y-2, F, H, K, V, X
J	U-6, B, C, G, I, K, L, V, Y
K	R-6, N-2, B, H, M, P, V, X
L	I-2, I, X
M	U-10, N-4, H, K, J, V, W
N	H-5, S-3, A-2, C-2, L-2, D, G, K, M, R, W, Y
O	G-6, D-5, S-2, B, F, H, P, U, V, Y
P	F-3, N-3, R-3, D-2, V-2, B, H, K, O, T, U, X
R	K-2, O-2, P-2, A, B, F, G, H, M, N
S	G-3, J-3, B-2, I-2, U-2, C, N, P, R, V, W, X
T	I-7, F-3, J-3, L-2, Y-2, X-2, N, P, V, Z
U	J-4, O-3, F, H, N, P, V
V	U-5, Y-4, N-4, J-2, K-2, F, P, T
W	N-4, H-3, M-3, Y-3, R-2, V-2, D, G, I, J, P, T
X	K-5, N-4, A-3, V-2, W-2, Y, Z
Y	T-6, N-3, J-2, F, H, L, P, R, V
Z	J-6, I-4, F-2, E, I, P, S, U, Y

[a]The numbers are a count of Ss who made each error at least once.

CHAPTER III

RESULTS

Report

In Fig. 2, the percentage of letters correctly reported (disregarding position) is shown as a function of the repetition number and the number of intervening rows. An increase in letters reported when a row is presented a second or third time is consistently found for all four conditions. Chi-square tests in the four conditions were used to compare repetition one vs. repetitions two and three combined for letters correct vs. letters omitted[1]. These tests yielded significant differences for the 0-intervening-row condition, $X^2(1)=11.61$, $p<.01$, and the 1-intervening-row condition, $X^2(1)=5.11$, $p<.05$; the differences were not significant for the 2-intervening-row condition, $X^2(1)=1.78$, and the 3-intervening-row condition, $X^2(1)=3.45$.

The number of intervening rows between repetitions can be seen to have only a slight effect on increases in report. This effect was in the expected direction that report increased less when there were more rows intervening between repetitions. Except for one point, the data for repetitions two and three are consistently ordered according to the number of intervening rows. The increases in report for the 0-intervening-row condition appear to differ only in degree from the increases for any of the other

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1. The chi-square tables for both report and recognition are accumulated in a manner such that individual Ss sometimes contributed data to all four cells. Therefore, the chi-square tests violate the independence condition for using chi-square statistics and their associated p values should be considered only as indicative of the relative size of the effects. These are given in lieu of presenting no statistical analysis.

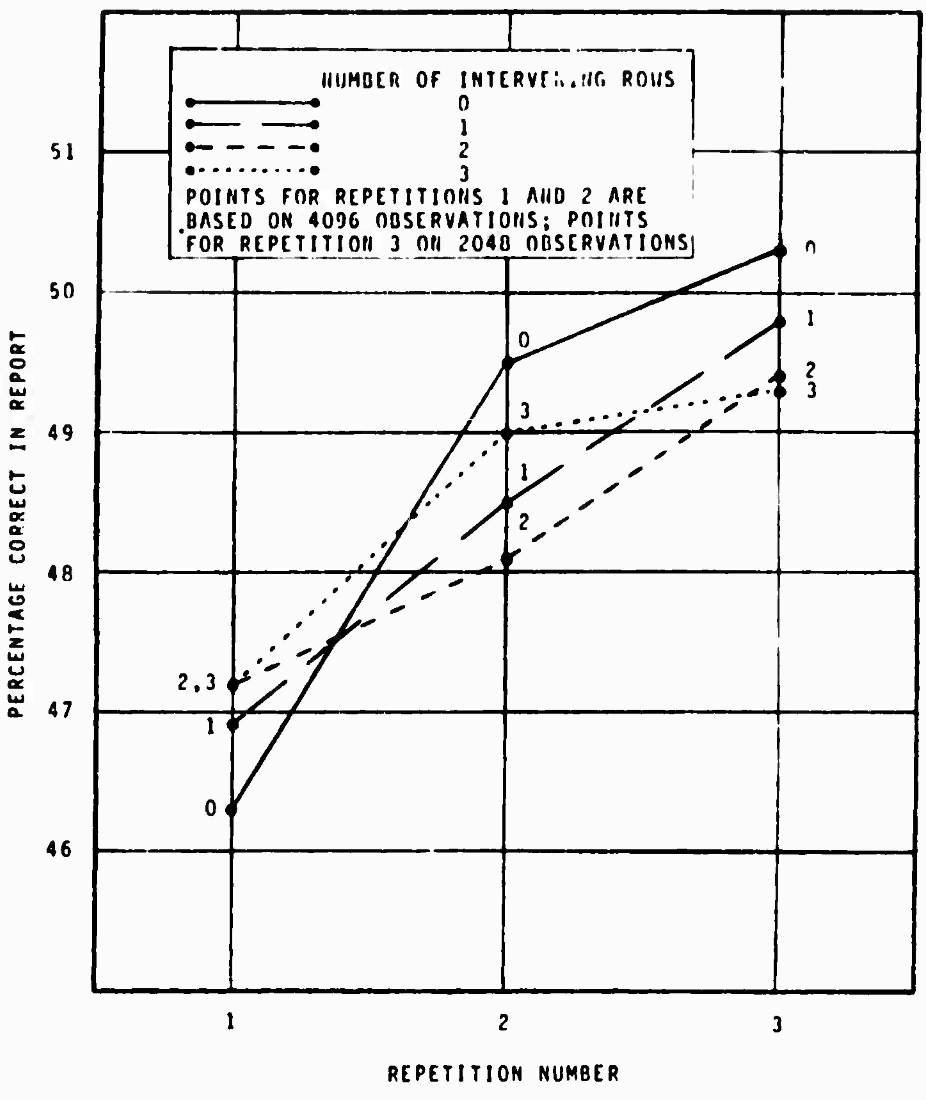


Fig. 2. Percentage correct in report as a function of the repetition number and the number of intervening rows. (Letters were scored correct if reported in any position.)

three conditions; they do not appear to be of a different kind. For instance, a chi-square test as between the 0-intervening-row condition and the 1-intervening-row condition on repetitions two and three is not even near significance, $X^2(1)=.55$. Therefore, the possibility can be rejected that the improvement in report is merely some kind of accumulation of activity with repetition, rather than a longer-term accumulation.

The increases in number of letters reported over three repetitions are quite small--on the order of 2 1/2%. Since it seemed possible that what Ss were learning with repetition was positional information, the increase of letters reported in the correct position was determined, but the results for letters reported in the correct position parallel those in Fig. 2, only 15% lower.

The nearest any of of Haber's conditions approached using random strings of letters was when he presented Turkish words to English-speaking Ss (Hershenson & Haber, 1965). In that condition the improvement over the first three trials was 30%, but that was measured in terms of the probability of reporting all seven letters correctly. While such a measure could amplify the percentages, it still is probable that the increases found here are much smaller than Haber's. This is most likely attributable to the Ss inability to anticipate when a row would be repeated in this experiment. Nevertheless, these results do replicate the finding that report increases with repetition for briefly displayed rows of letters, and extends the finding to situations where random strings of letters are presented and where the S is prevented from knowing when a row will be repeated.

Fig. 3 shows the correct report percentages for each repetition number as a function of the position in the row. Improvement in report is fairly uniform across all positions, but the increases in percent correct are slightly (non-significantly) greater for positions one through five (2.9% on the average) than for positions six and seven (.9% on the average). (These averages are the change in percent correct between repetition one and repetitions two and three taken together. Repetition two contributed twice as many points as repetition three, and thus is weighted twice as much in the averages.) Hence, improvement in report is as large or larger in that part of the row where the S focused his eyes and where report was fairly high initially, as in that part of the row where report was low initially.

Recognition

Fig. 4 shows the effect of repetition on recognition of letters as a function of whether the incorrect choice was an AC or a VC. The top two curves show the effect of repetition for all recognition trials, whether or not the letter was reported in the recall phase of the trial. Here again, the overall increase with repetition over three trials is just over 2 1/2%, but all of the increase is attributable to correct choices over VCs, which increased by just over 5%. By a chi square test comparing repetition one to repetitions two and three for correct vs. wrong, the increase in recognition over VCs is significant, $X^2(1)=6.14$, $p<.05$.

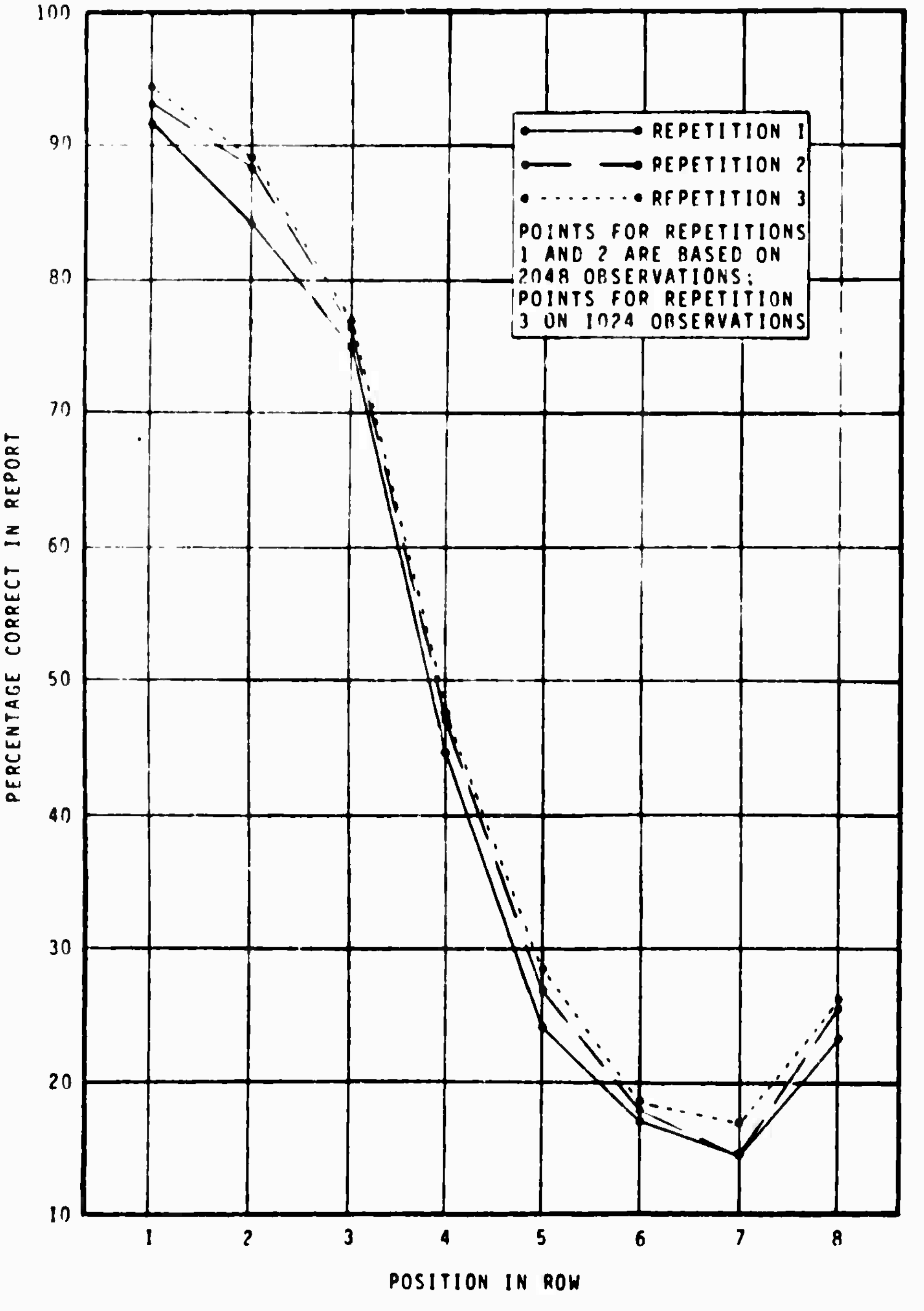


Fig. 3. Percentage correct in report as a function of the position of the stimulus letter in the row and the repetition number. (Letters were scored correct if reported in any position.)

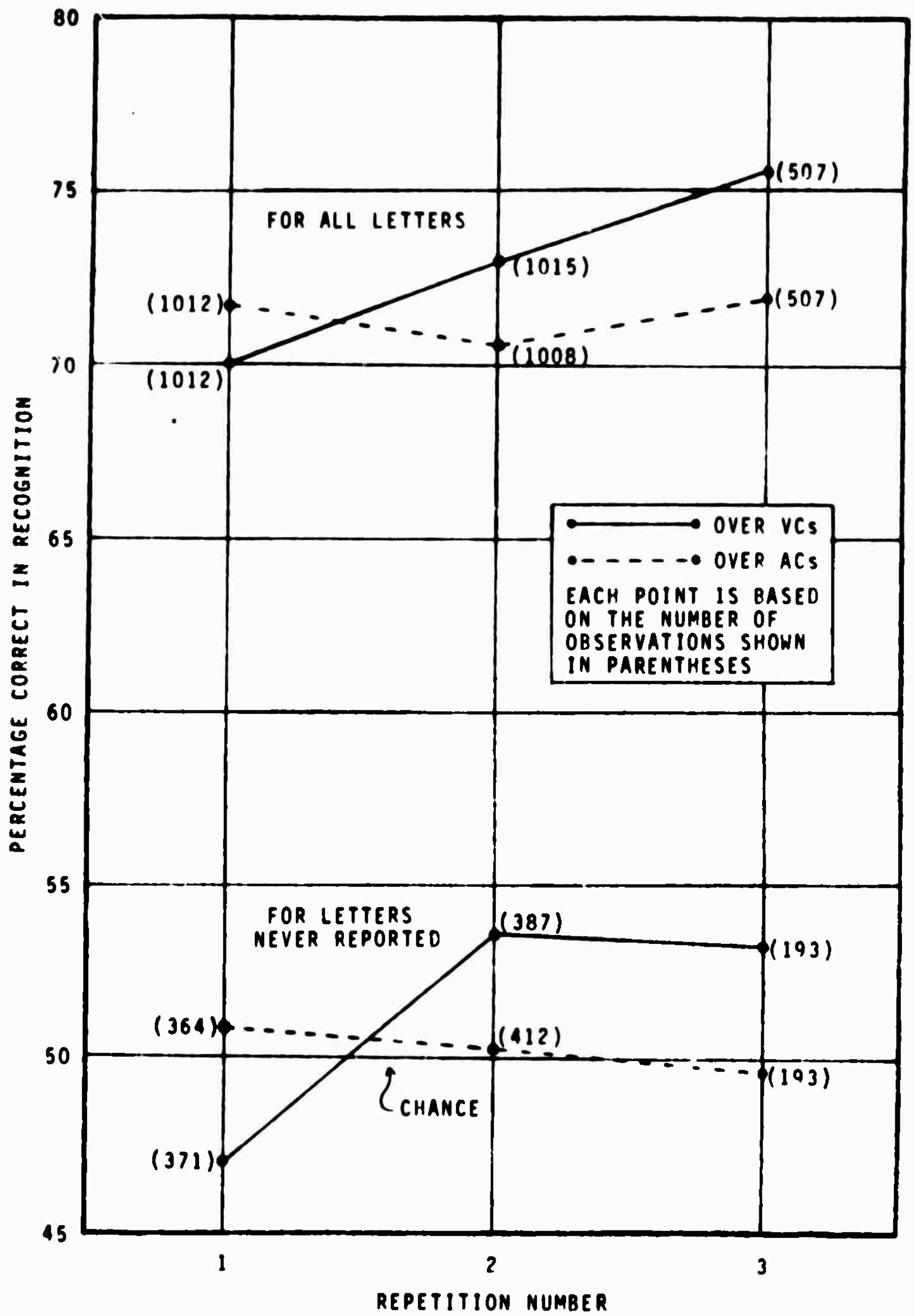


Fig. 4. Percentage correct in recognition as a function of the repetition number and whether the incorrect choice was a VC or an AC. The two top curves are for all the letters tested with repeated rows and the two bottom curves are for letters never reported on any of the repetitions of a repeated row.

The bottom two curves in Fig. 4 are recognition percentages for letters never reported on any of the repetition trials. Again there is an increase of correct choices over VCs and none over ACs. By a chi-square test comparing repetition one to repetition two and three as before, the increase in recognition over VCs for letters never reported is significant, $X^2(1)=4.42$, $p<.05$.

Fig. 5 shows the effect of repetition on recognition when the letter was not reported on the current trial (though it may have been reported on other repetitions of the same row). These curves are based on more data points than the curves at the bottom of Fig. 4, and show even larger increases in recognition over VCs for non-reported letters. To the degree that these curves are biased (a selectional bias) by the fact that letters recognized on early repetitions are likely to be reported on later repetitions, they would have been biased against showing any improvement. Thus, these increases are not artifacts. Again, a chi-square test comparing repetition one to repetitions two and three together shows a significant increase in recognition over VCs for non-reported letters, $X^2(1)=5.57$, $p<.05$.

If there were a general increase over the experimental session in ability to recognize non-reported letters, this effect could contribute to the increase found over repetitions. Though the percentage of non-reported letters correctly recognized rises very slightly during the first half of the session, it falls by a greater amount during the last half of the session. Thus, no such artifact can be contributing to the increases found.

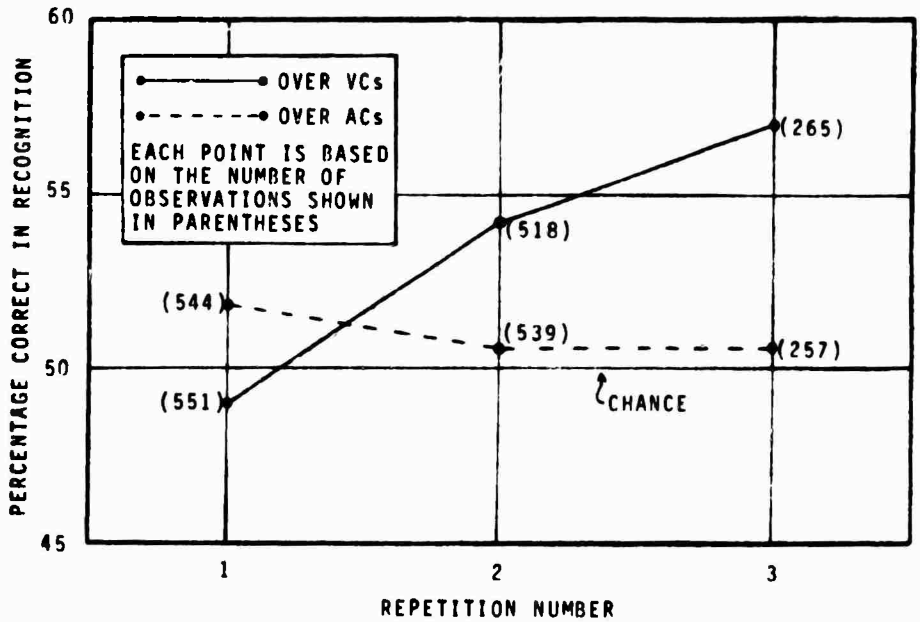
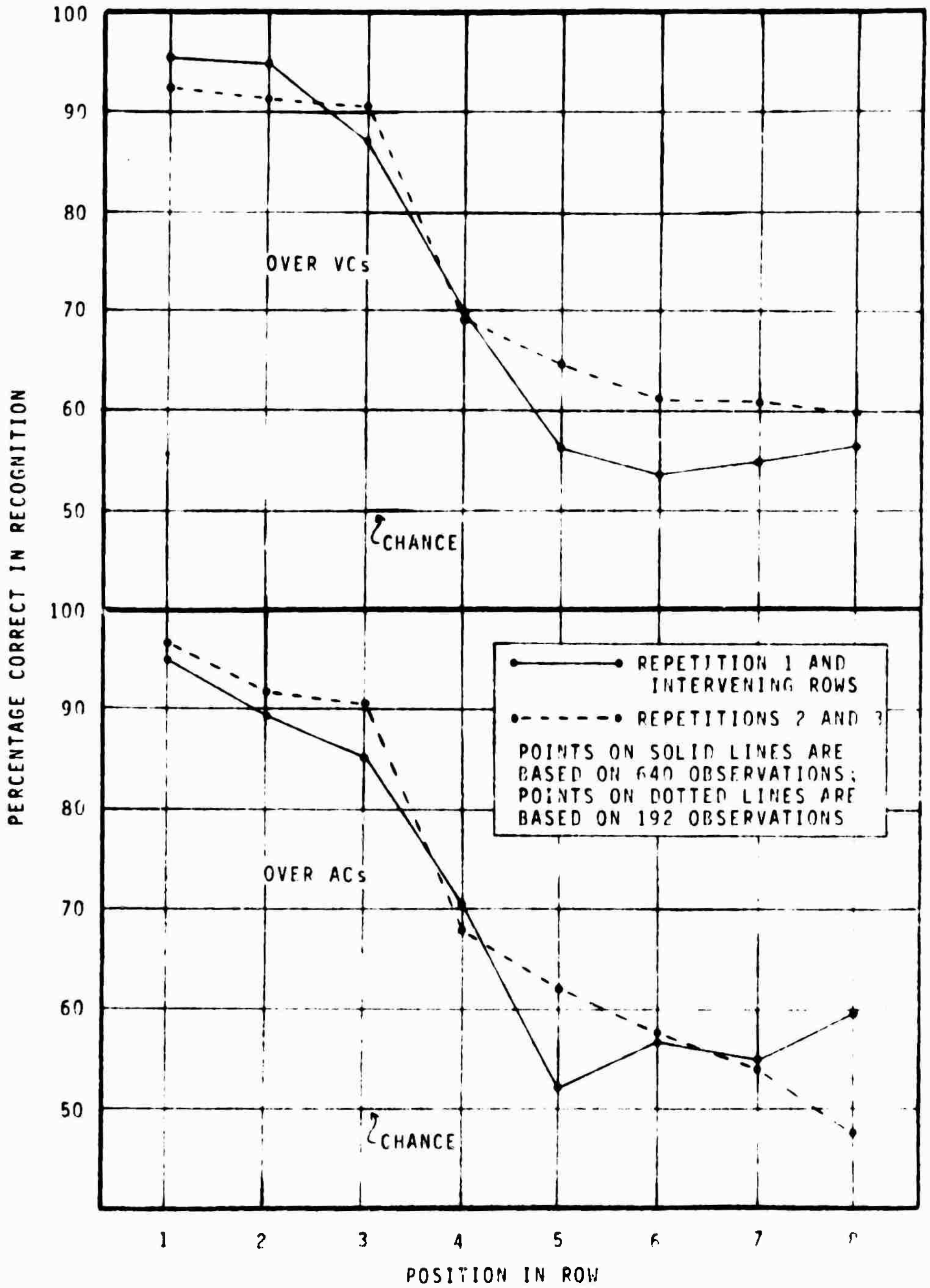


Fig. 5. Percentage correct in recognition as a function of the repetition number and whether the incorrect choice was a VC or an AC. The two curves are for letters not reported on the current repetition of a repeated row.

In Fig. 6, which shows recognition percentages for both reported and non-reported letters, one can see in which positions the improvement in recognition over repetitions occurs. The figure at the top shows that the increase with repetition for recognition over VCs occurs in the last four positions. This effect holds for non-reported letters as well, though the graph is not included. The increases over VCs for positions five through eight is significant by chi-square tests for all letters and for non-reported letters, $X^2(1)=10.39$, $p<.01$, (the same by coincidence in both cases). In contrast, the effect of repetition on recognition over ACs is small, as is shown in the bottom part of Fig. 6. There is improvement with repetition over ACs for all letters in the first three positions which is significant by a chi-square test, $X^2(1)=4.88$, $p<.05$. Similar improvement with repetition in the first three positions occurs for non-reported letters, but it is not significant, $X^2(1)=1.81$. Thus, the pattern of improvement over VCs and over ACs is very different, as is discussed later.

In a comparison between recognition over VCs and ACs on intervening rows, for both reported and non-reported letters, overall recognition over VCs is higher, as can be seen in Fig. 7. This difference is wholly a result of letters correctly reported but then confused in recognition, because recognition for reported letters is significantly higher over VCs than over ACs, $X^2(1)=13.18$, $p<.01$, whereas recognition for letters not reported is slightly (non-significantly) higher over ACs than over VCs. This explains the fact that in Fig. 7 it is in positions two through five



6. Percentage correct in recognition for all letters as a function of the position of the stimulus letter in the row and whether the row was seen for the first time (Repetition 1 and Intervening Rows) or for the second or third time (Repetitions 2 and 3). The two top curves are for recognition of letters when the incorrect choice was a VC and the bottom curves for recognition of letters when the incorrect choice was an AC.

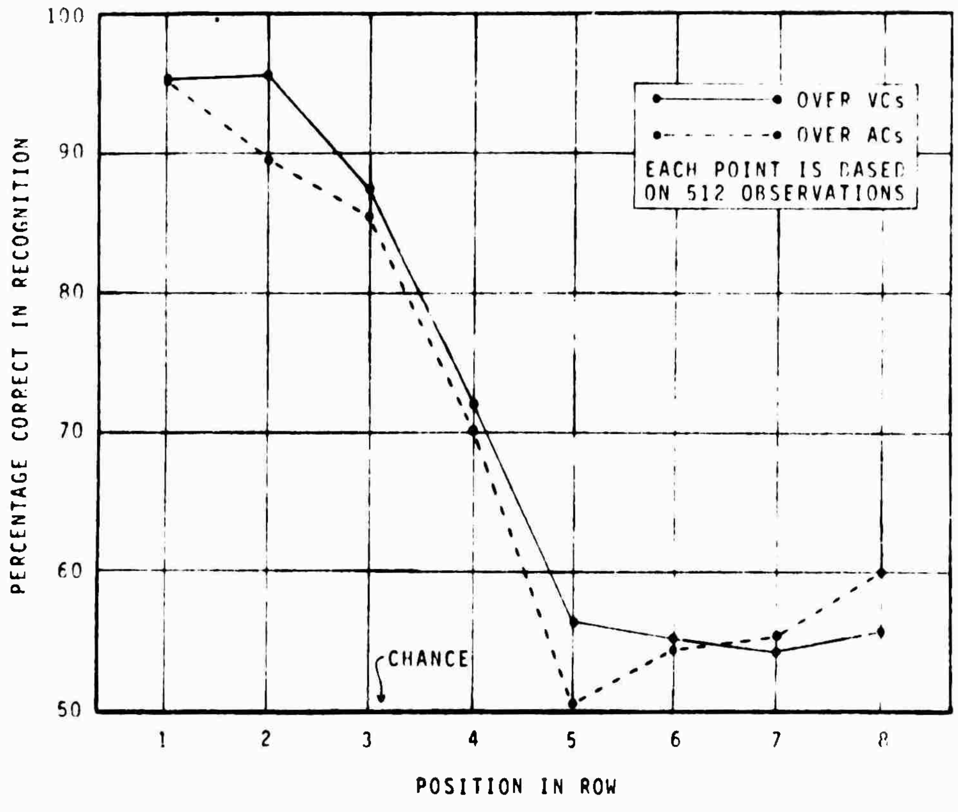


Fig. 7. Percentage correct in recognition for all letters on intervening rows as a function of the position of the stimulus letter in the row and whether the incorrect choice was a VC or an AC.

that recognition over ACs is significantly worse than over VCs, $X^2(1)=8.34$, $p<.01$. Since, except for position one, these are the positions where report was highest, the number of letters confused in recognition after correct report would also be highest. That position one was an exception implied that the first letter is not very likely to be confused between report and recognition.

Improvement in recognition, unlike that in report, was much more evident in the 0-intervening-row condition than in the other three conditions. Fig. 8 shows the percent correct in recognition for letters not reported on the current trial (as in Fig. 5) broken down with respect to whether there were intervening rows or not. There is improvement over both ACs and VCs for the 0-intervening-row condition, $X^2(1)=2.33$, not significant, but improvement only over VCs for the conditions with one, two, and three intervening rows, $X^2(1)=3.97$, $p<.05$. If ACs and VCs are averaged together, there is essentially no improvement for the intervening-row conditions. Thus, the recognition data do not rule out the possibility that improvement in recognition may have been based on an accumulation of activity, such as Haber (1967) has suggested, rather than a longer-term accumulation.

Effect of Report from One Row on Report of the Next Row

Fig. 9 shows the conditional probability of correctly reporting a letter given that the same letter was correctly reported in the previous row. The two curves show the effect of positional information on these

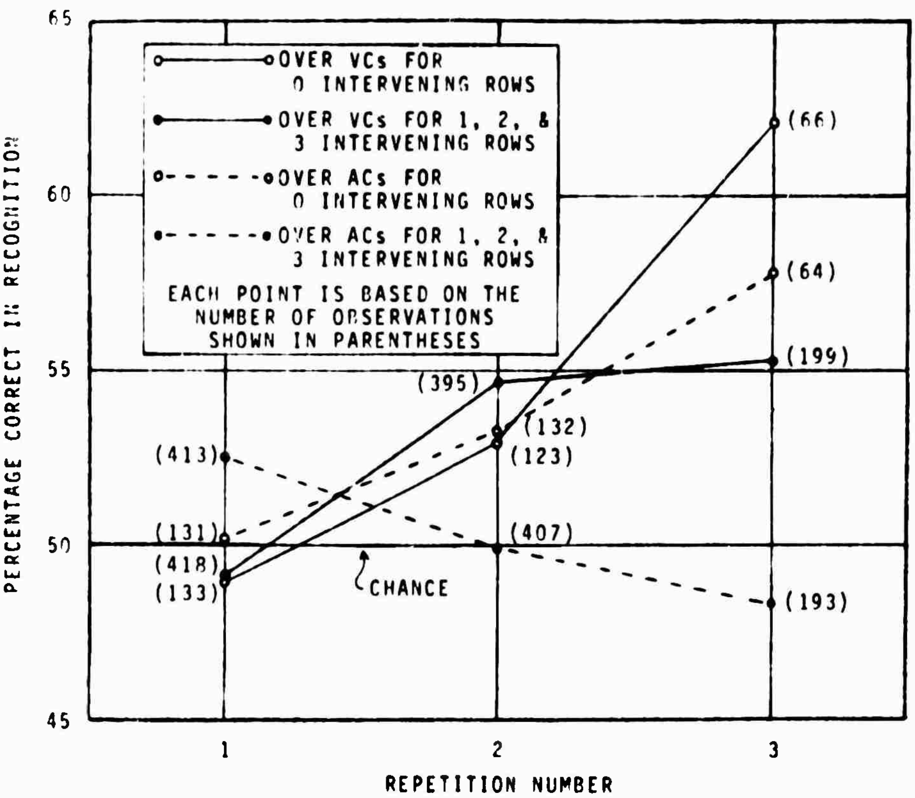


Fig. 8. Percentage correct in recognition for letters not reported on the current trial as a function of the repetition number, whether or not there were intervening rows, and whether the incorrect choice was a VC or an AC.

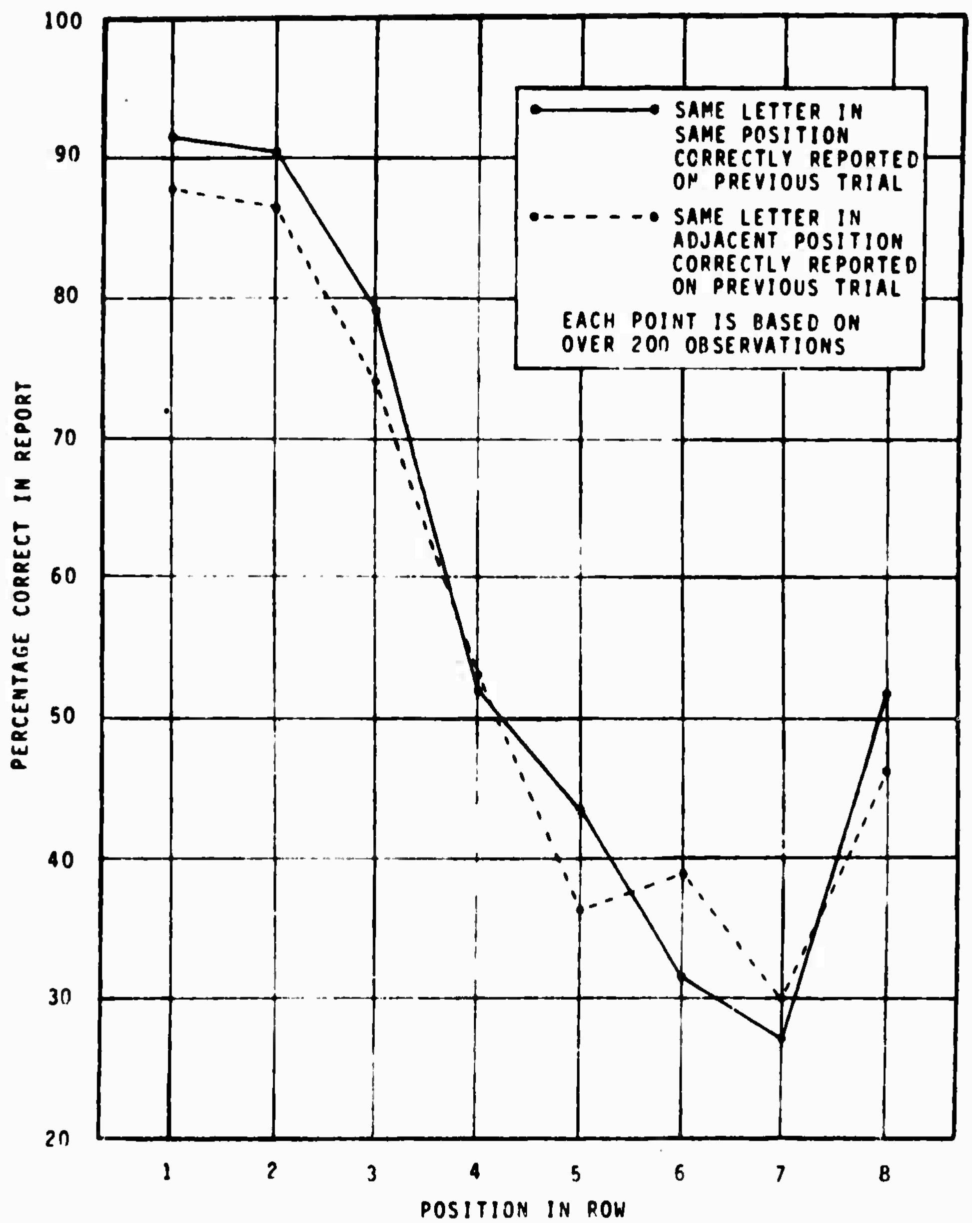


Fig. 9. Percentage correct in report as a function of the position of the stimulus letter in the row given that the same letter appeared in the same position on the previous trial and was correctly reported or that the same letter appeared in an adjacent position (n+1 or n-1) on the previous trial and was correctly reported. (The curves are based only on rows seen for the first time.)

conditional probabilities. One curve (the solid line) is the conditional probability of correctly reporting a letter given that the same letter was presented in the same position and was correctly reported on the previous trial. The other curve (the dotted line) is the conditional probability of correctly reporting a letter given that the same letter was presented in an adjacent position and correctly reported on the previous trial. These conditional probabilities exclude all repeated rows on repetitions two and three. To the degree that any facilitation from one row to the next is positional in nature, then the first curve (the solid line) should be above the second curve (the dotted line).

A priori one would expect positional information to be strongest at the beginning of the row where the S was told to focus his eyes, and perhaps in the last position because of an end effect. It is precisely in those positions where the first curve (the solid line) is higher than the second (the dotted line). A chi-square test comparing the two curves in positions one, two, three and eight falls just short of being significant, $X^2(1)=3.03$, $p<0.1$. This difference suggests there is a positional nature to any accumulation that occurs, since otherwise the facilitative effect of repeating a letter on the following trial should be position independent. In positions four through seven the facilitative effect is as strong from an adjacent position as from the same position, which indicates how weak positional information is in this part of the row.

The fact that these conditional probabilities are much higher in positions five through eight than the correct report percentages, as in Fig. 3, is

probably due mostly to the very strong selectional artifacts involved in such conditional probabilities. These artifacts are based on the fact that some letters are more likely to be reported than others, and some _S_s are more likely to report a letter shown in a given position than other _S_s. Thus, if a given letter is reported in the seventh position by a given _S_, it is highly likely that he would report that same letter in that position on a succeeding trial independent of any facilitative effect from his previous report. Such artifacts in general obviate the usefulness of conditional probabilites, though they would not contribute to the differences shown in Fig. 9 nor to those shown in Fig. 10, which is presented in the next section.

CHAPTER IV

DISCUSSION

The Improvement with Repetition

The results of this study revealed a flaw in the logic behind one of the original hypotheses (p. 11-12) of this study. This hypothesis was that an accumulation of visual information with repetition should lead to a greater increase in correct recognitions over ACs than over VCs for non-reported letters. This prediciton was made because any partial visual information that accumulated should be more useful in distinguishing a correct letter from an AC than from a VC. The problem with this argument lies in the fact that recognition of non-reported letters in most cases would not be based on accumulating visual information, if Sperling's (1963) hypothesis is correct that the auditory rehearsal loop is the limiting factor in report, when more than four or five letters are presented at one time. If report is limited by rehearsal rate, than any visual accumulation with repetition would lead to an increase in the number of letters that are started off in the rehearsal loop, but then are lost before they can be reported. That is to say the fixed capacity of four or five letters in the rehearsal loop will be overloaded by the additional letters seen on trials with repeated rows, and hence most of these additional letters will be forgotten before there is time to write them down. If any fragmentary traces were left from these additional letters started off in rehearsal, but not reported, these traces would be auditory traces. Fragmentary

auditory traces (e.g., the letter had the phoneme ē), however, would be more useful in the recognition test for distinguishing the correct letter (e.g., V) from a VC (e.g., Y) than from an AC (e.g., B). Hence, if the number of letters seen increases for repeated trials, but there is a rehearsal limit preventing a corresponding increase in the number of letters reported, then there will be a greater increase of recognition over VCs than over ACs.

This then leaves two possible explanations of why there was an increase in recognition percentage over VCs and none over ACs. One explanation, compatible with the visual accumulation hypothesis, is that repetition increases the amount of input information (or letters seen). Because the *S* sees more letters with each repetition, he starts rehearsing more letters. Most of these additional letters are lost before they can be reported, though there is some improvement in report. There are, however, enough fragmentary traces from them left in auditory memory to allow the *S* to distinguish additional letters from VCs, but not from ACs.

The other explanation would be the obverse of the original hypothesis. In this explanation, the *S* does not see more letters with each repetition. Instead, repetition of a row allows the *S* to rehearse more letters, because the auditory accumulation from the previous trial has led to some *response integration* of the string of letters. Some of these additional letters are lost before report and so fragmentary memory traces are left in auditory memory just as in the first explanation. The point to be emphasized is that whether the accumulation that leads to an increase in letters rehearsed takes place in auditory or visual memory will not matter if the

S's recognition depends upon the fragmentary traces left from letters lost in rehearsal. In either case, the improvement will be greater over VCs than over ACs

There are two pieces of evidence, though, which suggest that the first explanation is the correct one. The first is that Haber found much greater improvement over repetitions with words as stimuli than found here with letter strings as stimuli. Because people tend to perceive words as a single unit, rather than as a string of letters, such stimuli are not likely to overload the rehearsal loop. Under the second explanation above there should not be much improvement with words as stimuli because there will be little or no response integration necessary for words. On the other hand, visual accumulation that led to an increase in input (or letters seen), as in the first explanation, should lead to large increases in report (which Haber found) because perceiving the stimulus as a word will reduce the load on rehearsal. In this study, even though the number of letters seen may increase substantially with repetition, the report would not increase very much because the rehearsal loop is overloaded.

The second piece of evidence that tends to support the first explanation is that the improvement over VCs in this study was found in the last four positions (see Fig. 6), whereas the improvement in report was fairly uniform throughout (see Fig. 3). If as Glucksberg, Fisher & Monty (1967) argue, the major effect of visual confusability is upon input rather than storage, we would expect improvement in input to be found mostly in the last four positions. This is because the Ss were focussing on the left end of the

string of eight letters and it would be the last four letters that would be most difficult to see. Thus, the pattern of improvement in recognition, which is quite different from that found in report, fits precisely the pattern that would be expected if there were more letters seen with each repetition. The kind of accumulation that would produce increases in the number of letters seen would most likely be a visual accumulation. While these two pieces of evidence are not entirely convincing, they do indicate that these results are at least compatible with the kind of interpretations Haber and Glucksberg, Fisher, & Monty have given to their data.

The differences in patterns of improvement for report and recognition suggest that there are two different kinds of improvement occurring. The improvement in recognition percentages may be a result of an accumulation leading to an increase in the number of letters seen initially. On the other hand, the improvement in report may be a result of response integration occurring with letters in rehearsal.

If the above discussion is correct, then there are two factors contributing to the difference between the large improvement with repetition Haber found for reporting words (about 30% over three trials) and the small improvement for reporting letter strings (about 2 1/2% over three trials) found in this experiment. Probably the major factor is that repetitions could not be anticipated in this experiment and could be in Haber's studies. Therefore, Haber's Ss would be predisposed to see the same letters on each repetition whereas the Ss in this experiment would not be. The second factor is based on the difference between encoding words and letter strings.

As suggested above, an increase in letters seen would decrease the load on rehearsal with words whereas it would increase the load on rehearsal with letter strings. Hence, to the degree the rehearsal rate limits the number of letters reported, the strings will show less increase with repetition than will words. This explanation could be tested in an experiment which systematically varies the encodability of the stimuli as between the letter strings used in this experiment and the words Haber used.

The Sperling Model

There are a number of aspects of the data that support the Sperling hypothesis that letters are transferred from visual to auditory memory where they are rehearsed, and that this rehearsal is the limiting factor in the number of letters that can be reported. The supposition that letters are transferred into auditory memory is supported by the fact that ACs are more likely to be mistakenly chosen in recognition than VCs when the letter was correctly reported (see Results section), while for letters not reported VCs are slightly more likely to be mistakenly chosen. If the letters were not transferred to auditory memory, there would be no reason for ACs ever to be mistakenly chosen more than VCs. Since report was written, the only obvious reason for the transfer is that letters can be rehearsed better auditorily. Rehearsal maintains them long enough to be reported, and so it is the reported letters that are most subject to auditory confusion.

Further support for the hypothesis is found in Fig. 6. Improvement in recognition percentages can be seen to occur over VCs (the top graph)

in the last four positions, whereas what improvement there is over ACs (the bottom graph) occurs in the first three positions. Therefore, it appears as if any improvement over ACs is a result of rehearsing the first few letters. That this rehearsal is the limiting factor in the number of letters reported gains support from the fact that the improvement over VCs in the last four positions (which as suggested earlier probably derives from an increase in letters seen) is not for the most part translated into improved report. This is evident from the fact that improvement over VCs is much greater in the last four positions whereas improvement in report is fairly uniform throughout (see Fig. 3).

Fig. 10 has much the same implication as Fig. 6. The curves in Fig. 10 show the probability of reporting a letter correctly given that the letter which appeared in the same position on the preceding trial was either visually or auditorily confusable with the letter shown on this trial. These conditional probabilities of correct report are based on the same set of ACs and VCs that were used in the recognition tests, as shown in Table 1. It is evident that ACs are most detrimental in positions two and three, $X^2(1)=3.12$, not significant, whereas VCs are most detrimental over the last three positions, $X^2(1)=7.54$, $p<.01$. This presumably is because the S rehearses the first few positions auditorily, and so the ACs from the previous row can lead to confusion in rehearsal on the current row (though not in the first position where little confusion is likely in any case). Visual confusability dominates in the last three or four positions because, as Glucksberg, Fisher, & Monty (1967) have argued, visual confusability

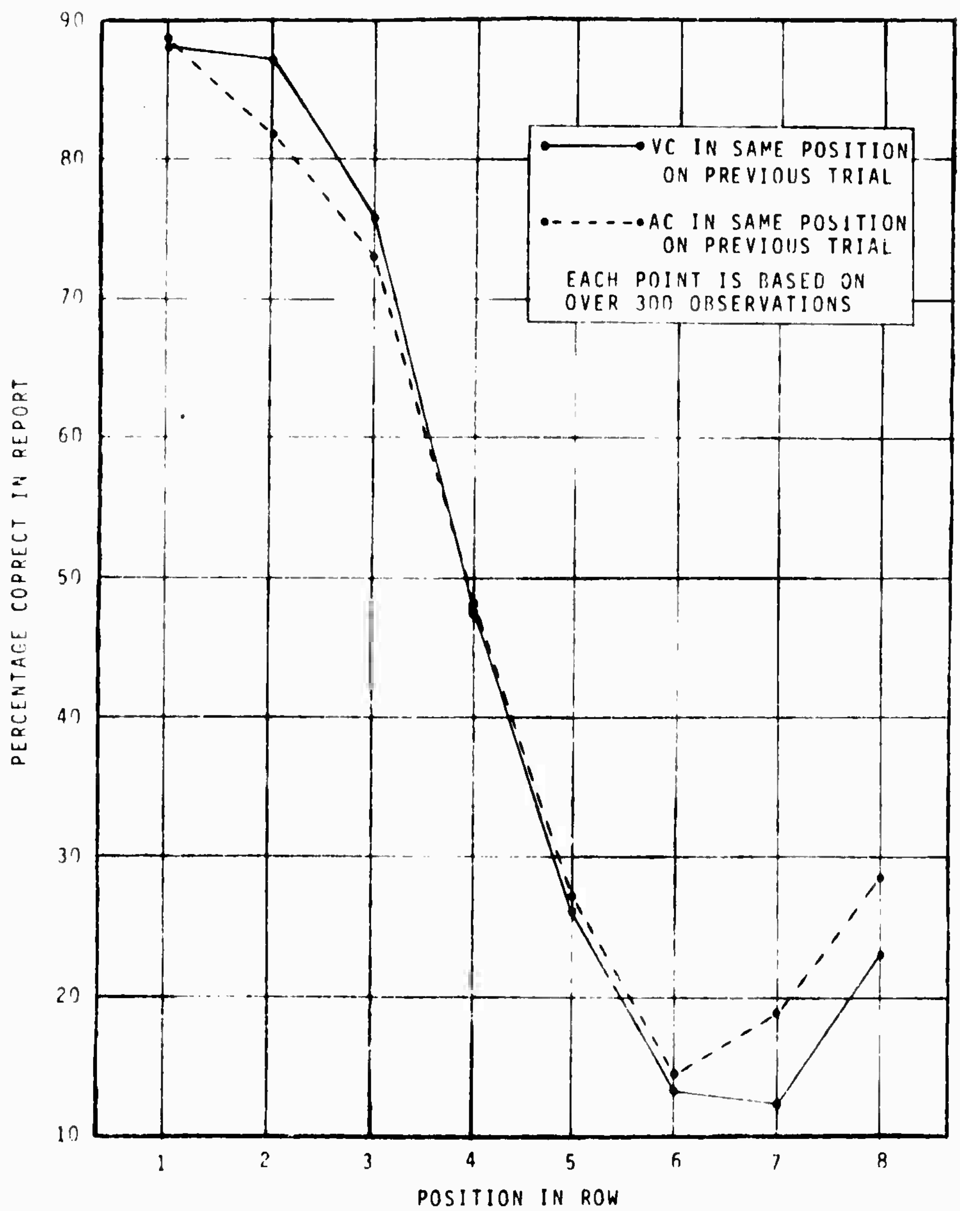


Fig. 10. Percentage correct in report as a function of the position of the stimulus letter in the row given that a VC or an AC occurred in the same position on the previous trial. (These curves are based only on rows seen for the first time.)

acts at the input stage. As pointed out earlier, it is at the end of the row where input confusability will be greatest, since the S was focussing toward the beginning of the row.

Conclusion

In this experiment there was improvement with repetition both for report and for recognition over VCs. The basis for the improvement appears to be quite different in the two cases, however. The improvement in recognition occurs toward the end of the row opposite where the S was focussing his eyes, and is most likely based on an increase in letters seen with repetition. This would be the kind of effect that Haber (1967) has found. It is not clear from this experiment whether this improvement stems from a transient accumulation of activity traces or a longer-term accumulation. An explanation in terms of an accumulation of activity traces would fit best with the general failure in the literature to find any long-term effects of stimulus traces. It well may be that for a long-term accumulation to occur, there must be rehearsal of (or attention to) the stimuli.

The improvement in report with repetition clearly occurs for intervening-row conditions, and must therefore be a long-term accumulation of some kind. It is similar to the improvement found in the Hebb (1961) and Melton (1963) experiments, and is probably based on response integration. The results supported the Sperling (1963) model in two respects: Apparently most Ss auditorily rehearse the letters in the row in order to report them, and it is this rehearsal that is the major limiting factor in the number of letters reported.

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